Les grands équilibres et les grands enjeux liés au cycle du carbone

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Résumé

Cet exposé concerne à la fois les changements globaux, les modifications du cycle terrestre du carbone et les différents enjeux qui y sont liés.

La première partie présente les problèmes liés au changement climatique qui sera l'événement environnemental qui aura le plus de répercussions au 21 eme siècle.
La corrélation est maintenant bien établie par les travaux du GIEC entre l'accroissement des émissions de gaz à effet de serre et en particulier l'élévation des teneurs en CO2 et le changement climatique constaté depuis un siècle. Si les scénarios concernant l'élévation de la température convergent, les incertitudes sont plus grandes sur les conséquences attendues du changement climatique et leur régionalisation. Des retombées positives sont espérées pour la production de biomasse et donc l'agriculture, mais elles seront contrebalancées régionalement par des perturbations des cycles en particulier du cycle de l'eau. Les phénomènes d'érosion et de désertification risquent d'être accrus et globalement le déséquilibre des ressources entre le nord et le sud du globe risque d'être accentué.

La deuxième partie concerne le cycle du carbone dans la biosphère continentale et plus particulièrement le rôle respectif des sols et de la végétation, les perturbations apportées par l'homme et les possibilités d'intervention au niveau des puits de carbone (forêts, agriculture).Cette partie restera générale dans la mesure où elle sera l'objet d'autres exposés.

Dans une troisième partie les grands enjeux du cycle du carbone sont replacés en considérant d'abord les conventions internationales issues de la conférence de Rio: changement climatique mais aussi biodiversité et désertification.
Les enjeux peuvent aussi concerner la protection des sols (communication sur les sols au niveau européen, écoconditionalité aux Etats Unis) et plus généralement l'élaboration d'une agriculture durable au niveau mondial.
Au niveau économique l'application des accords de Kyoto peut constituer un cadre intéressant, mais il serait nécessaire d'étendre les MDP à l'agriculture, et de développer un marché du carbone au bénéfice des pays du SUD, ceci afin de lutter contre l'érosion, la dégradation des sols et la désertification.

Mots clés : Changement climatique, Causes et conséquences, Cycle du carbone, Puits et sources, Conventions internationales (climat, biodiversité et désertification) ; Séquestration du carbone, Accords de Kyoto, Mécanismes de développement propre, Marché du carbone.

Global change and carbon cycle: which place for the soils and agriculture

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Abstract
This presentation is a general paper which replaces the role of carbon, soils and agriculture, referring to the global and climate change. In this perspective, carbon sequestration in soils, appears as an effective but limited mean to decrease the greenhouse gas effect, but also as a solution to induce a better way to prevent the effects of climate change. In order to sequester carbon, new agriculture systems have to be developed which appear more sustainable because they protect the soil against erosion, desertification, with an increase of soil biodiversity.
Key words: climate change, erosion, desertification, biodiversity, conservation tillage, conservation agriculture, carbon sequestration.

Introduction

Global change will be the most serious environmental preoccupation for the 21 th century (IPCC 2001). The change in the climate has yet begun with a global increase in temperature and even if there are different scenarios, the evolution will pursued at less until the end of the century. The consequences will be important and could be positive but mostly negative.

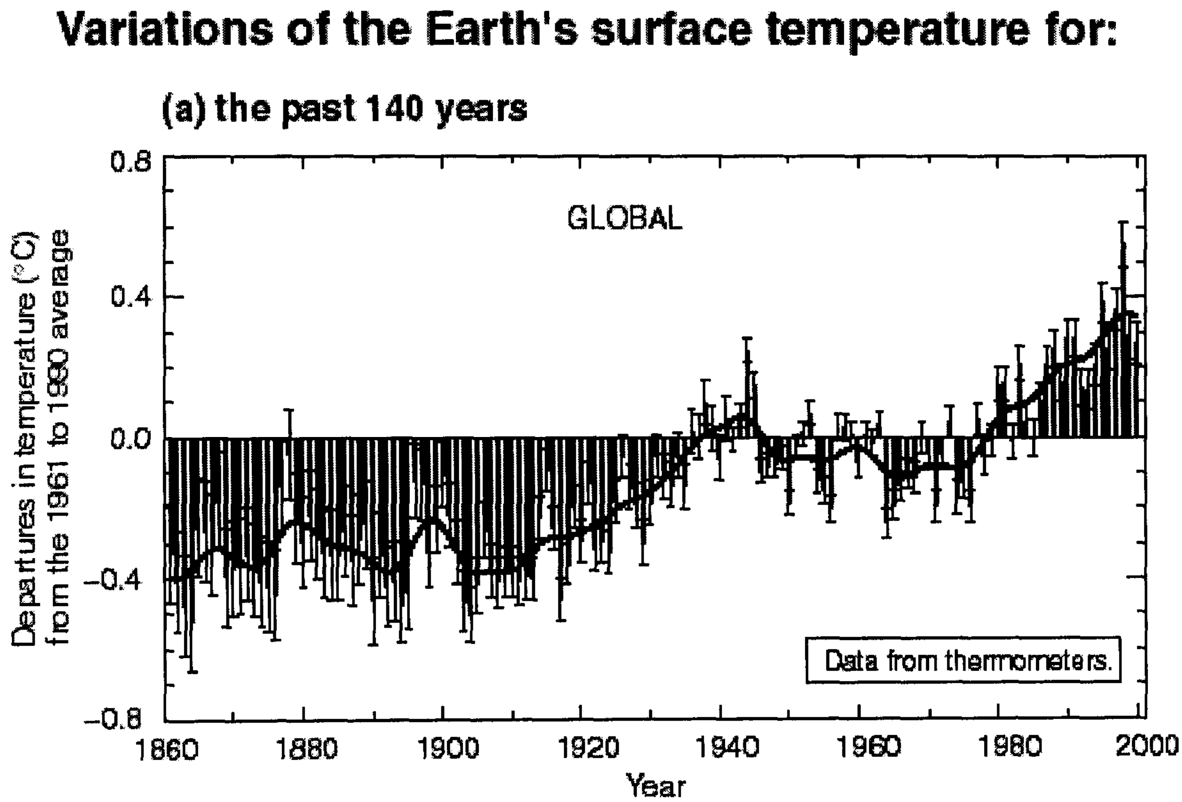
The carbon cycle has a key position in this global change either for the causes or the solutions of remediation.

The stakes can be replaced in the general context of international conventions and of the sustainable management of the land by agriculture.

I Climatic change: causes and consequences

If we refer to the last IPCC report (2001) on climatic change, the increase in temperature of +0,6 degree C is well established over the 20th century (figure 1) and the projections for the 21 th century with all a range of scenarios result in an increase surface temperature of 1,4 to 5,8 °C (even stronger for the north). If natural causes have played a great role to explain the precedent historical variations (for example what is called le petit age glaciaire), the recent increase in temperature is now well correlated with human cause and especially with the increase of different greenhouse gases: CO2, CH4, N20 (figure 2). The respective emissions by the different countries is also well known; for example CO2 emissions in 1995 were of 1400 for USA and more than 800 for China and Europe (15 countries). The main problem is that all the emissions are increasing, even if the international convention on climate in Rio(1992) has decided to stabilise them; for the short term, even if the Kyoto protocol was applied by every industrialised country (-5,2% of emission reduction on the basis of 1990), it would not be sufficient.

Figure 1 Variations of the earth 'surface temperature for the past 140 years (IPCC, 2001)



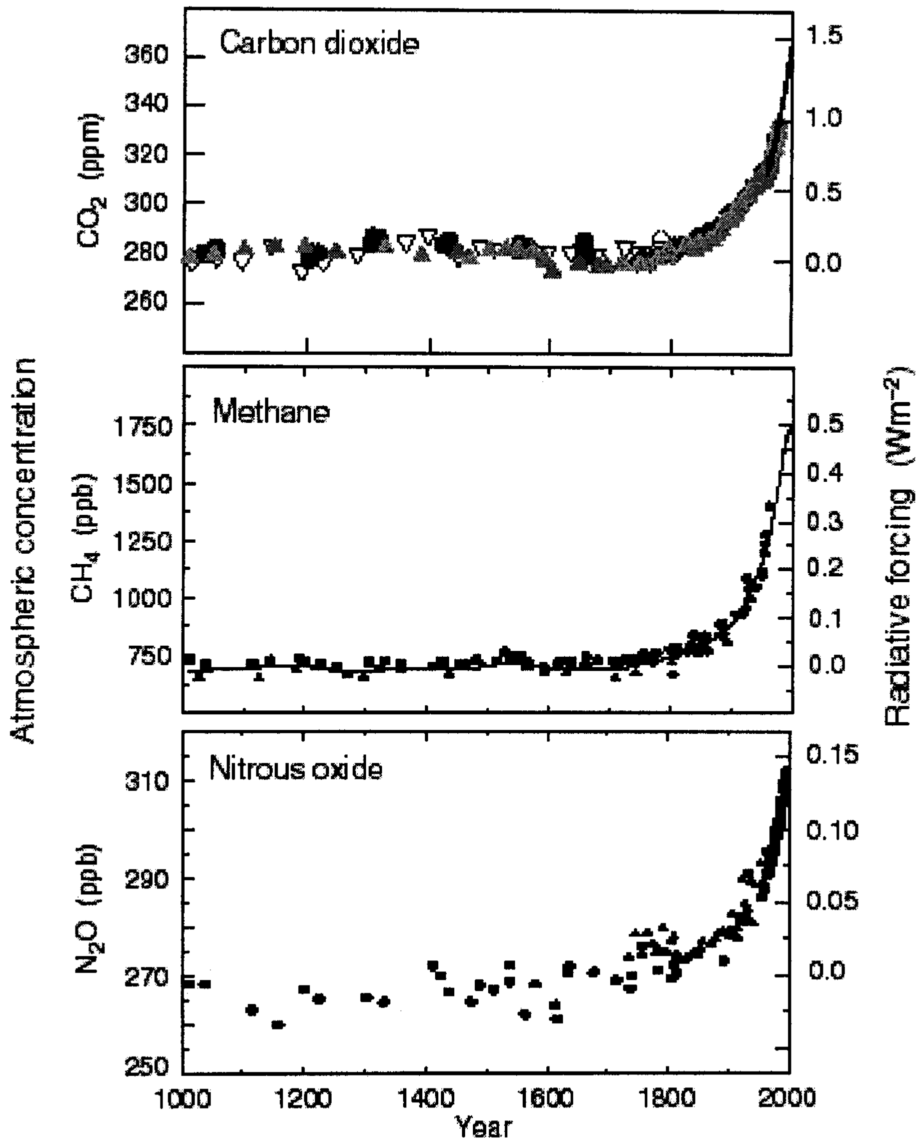


Figure 2 Variation of the atmospheric concentration of the main greenhouse gas (IPPCC, 2001)

What are the main consequences? As we have said the first consequence is the increase in temperature which has yet an important effect in boreal sub boreal and alpine area, with a destabilisation effect on both vegetation and soil (organic matter). In sub humid, or semiarid area, the increase in evapotranspiration can increase the water deficit and favour the desertification process. The other effects on precipitation is difficult to predict and only the trends are known, with an increase by 5 or 10 % over mid and high latitudes of the northern hemisphere continent and a decrease near the tropics. More heterogeneity in droughts and rains is also predicted which will have important effects on runoff, erosion and flood.
If the effect on biomass production (and yield) is considered, the increase in CO2 concentration can be favourable with an increase of yield (10 % for cereals, 25 % for grasslands and even 30 % for trees), with a lot of change in phenology. This will occurs if water and nutrients are not missing; this could be the case when irrigation is needed and for acid tropical or forest soils which are very poor.
Even if a lot of uncertainties do exist, we can predict that climate change will induce great perturbation and will certainly increase the unbalance which yet exists between north and south part of the world.

II Carbon cycle in the continental biosphere

In a global carbon cycle (figure 3), soil with 1500 to 2000 Gigatonnes (Gt) depending the soil depth, and vegetation mainly perennial with 600 to 700 Gt C appears as the main C stocks.
Vegetation and soil can be either sources or sinks for carbon. In the past before the industrial development in the 20th century, deforestation and land cultivation were the main sources of green house gas emission; now they are still a source of 1,7 to 2 Gt per year issued mainly by the deforestation of 10 to 15 Millions ha in the south part of the world. The use of fossil carbon is now the main source of CO2 and it is well known that the reduction of this source represents the only long term solution and that all the other solutions which will be evocated are short term or complementary solutions.
An important point to consider is that a part of the CO2, not far from 2Gt, is yet being stored in the continental biosphere (vegetation + soil). So the biosphere seems to act naturally as a carbon sink and the challenge is to know if this sink can be increased by human action.
Such intervention is included in the Kyoto protocol; article 3.3 considers the role of reforestation and afforestation in the net changes in greenhouse gas (with quotas established for the different countries); article 3.4 concerns similar changes in the soil in relation with agricultural soils, the land use changes and forestry(IPCC 2000). In the conference of parties of Bonn (and Marrakech) it was accepted without limitation of tonnage and surface, but a lot of questions are still raised about the amount of C which could be stored and the verification of the changes.

A Stocks and fluxes

Different factors determine the natural C stock repartition. At the world scale, biomass production (Robert and Saugier 2003) is an important factor correlated with rainfall which induces soil organic matter (SOM) distribution by major ecological zones (table 1 from Batjes 1999). High C contents are associated with humid forest soils. But low temperature explains the highest stocks in the boreal zone or in mountain area, and water accumulation is the main factor of peat formation. Soil type and properties (for example texture) explain also what can be called the initial soil carbon content.

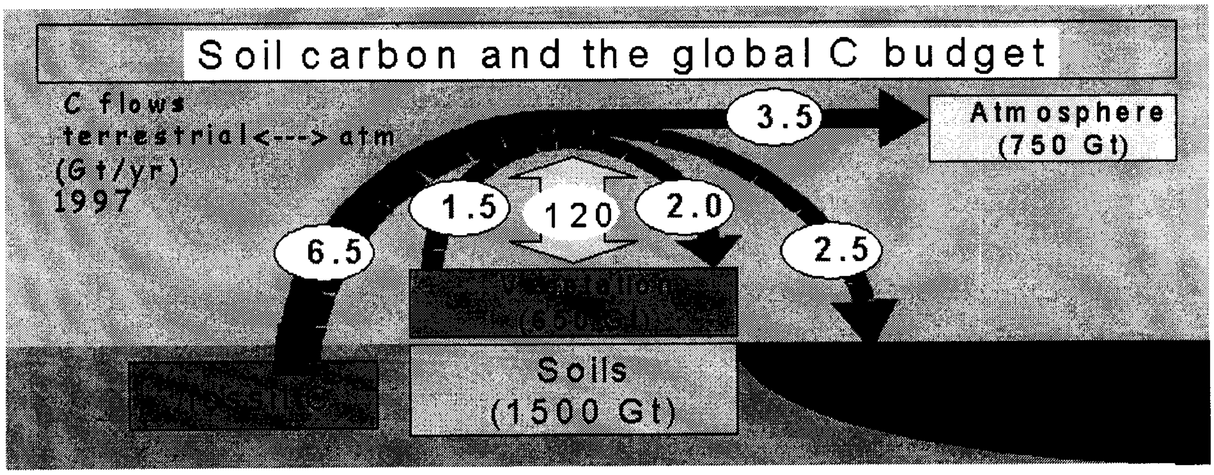
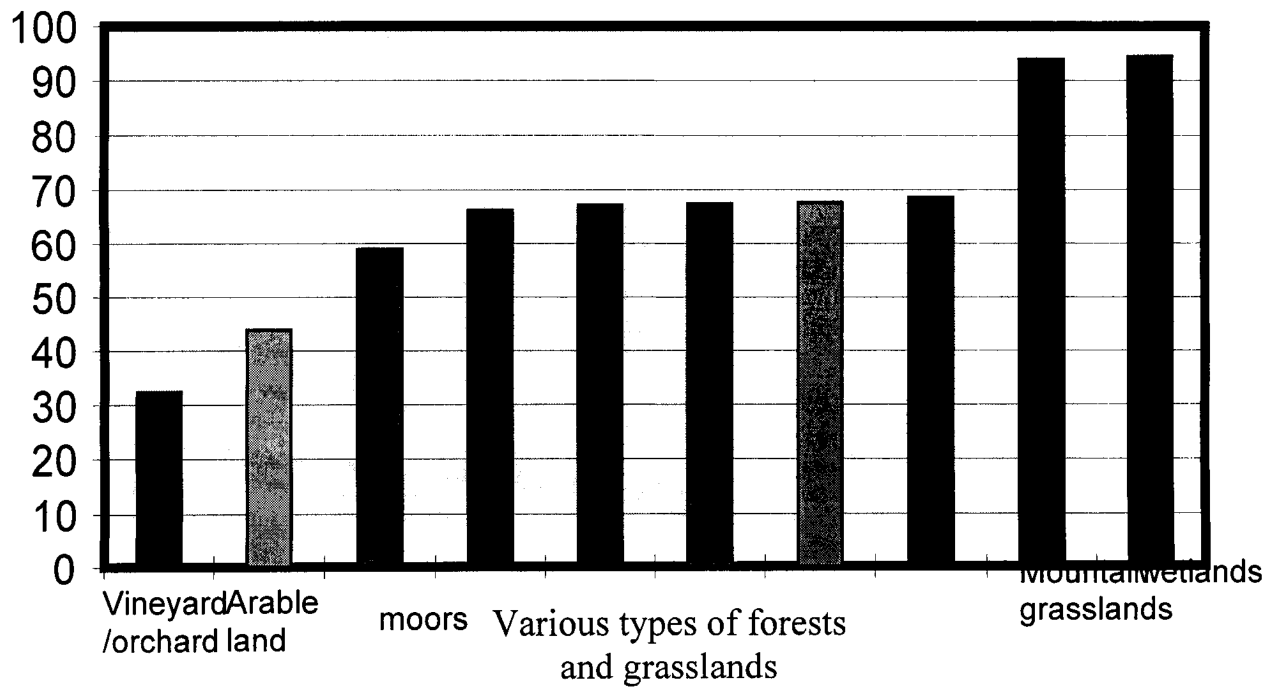


Figure 3 the terrestrial carbon cycle

Figure 4 Variation of soil C content (t /ha for 30 cm depth) with soil cover and soil use

10^3 kg/ha (0-30 cm)



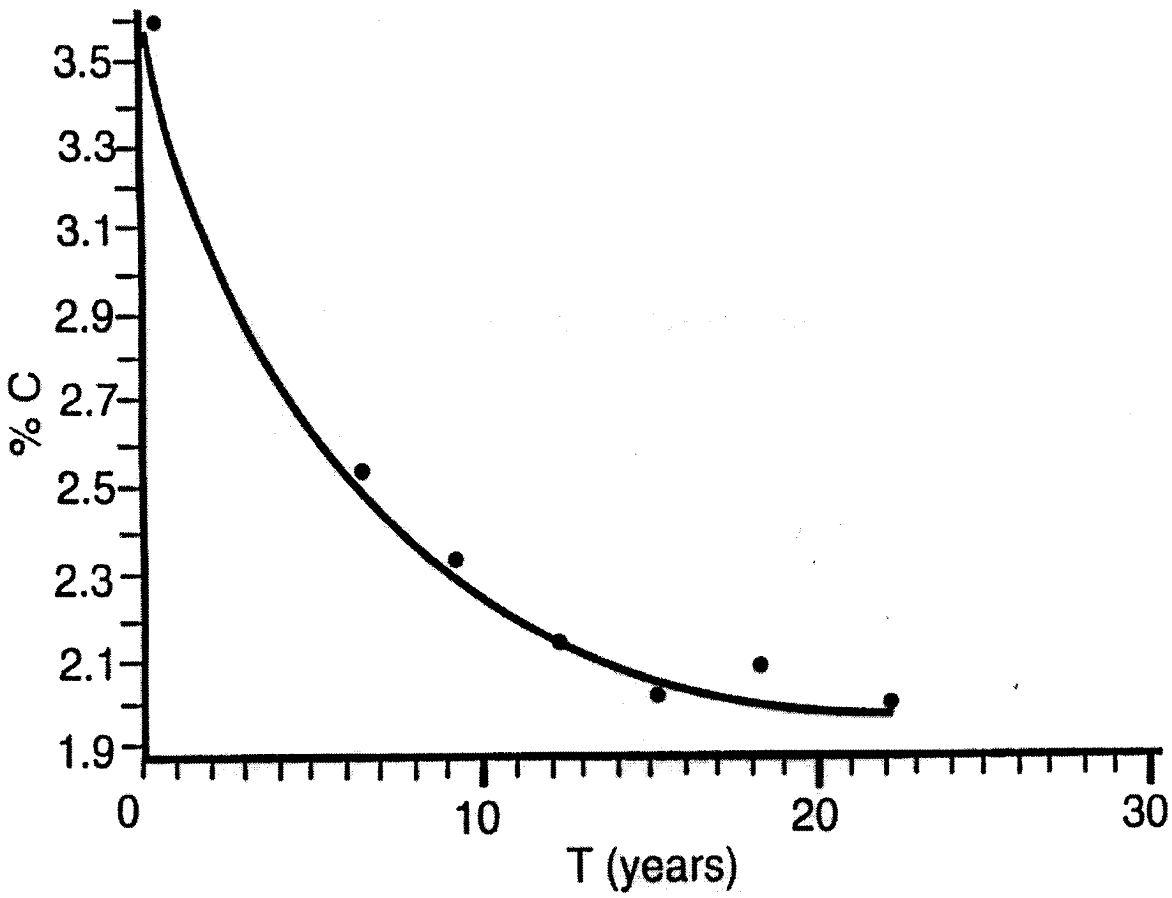


Figure 5 : Carbon evolution in the Rothamsted Highfield grass-to-arable conversion experiment (from Johnston, 1972).

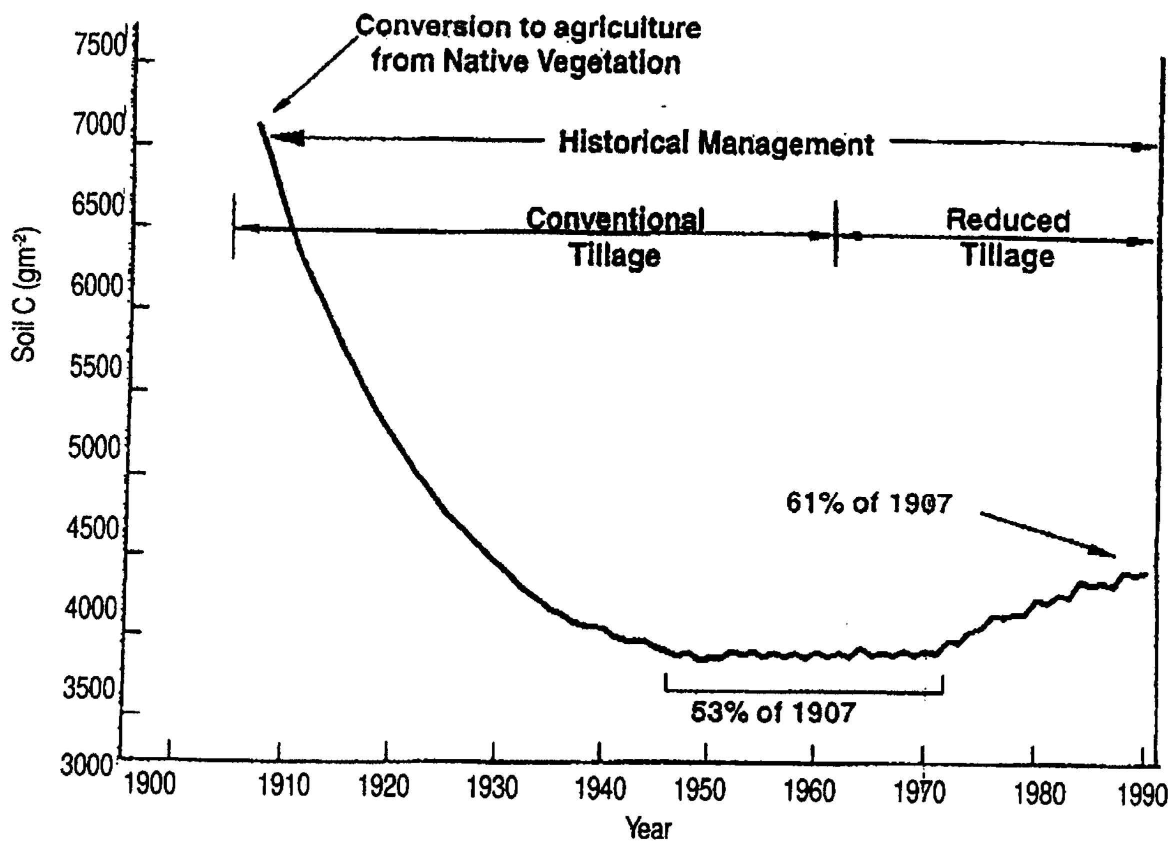


Figure 6: Simulated total soil carbon changes (0 to 20 cm depth) from 1907 to 1990 for the central U.S. corn belt (from Schmit, 1999).

Entropic factors such as land use, land cover, and agricultural practices are the main factors governing actual C state in soils. This is well illustrated by the C content of French soils (Arrouays and al 2001) which ranges from more than 100 t /ha for some natural soils to 30 t/ha in arable or vineyard soils (figure 4).These low values are explained by the important loss of C which occurs during the first years of soil cultivation of grassland or forest soils, mainly in relation with tillage(figure 5).
So one can estimate that arable lands have lost around 40 % of their carbon content in less than 50 years; a nice illustration is brought by the soil evolution of the corn belt in US (figure 6).Such effect of tillage can be explained by what can be called the de-protection of soil organic matter physically protected inside the soil structure. (Balesdent et al 2000); the result is an increase of mineralization with a flux of CO2 emission (Reicosky et al 1995)
Considering the possible influence of the increase of temperature on C mineralization of organic soils of the northern part of the world and the great influence of deforestation in the southern part, it could be very important to find the way to protect them or to develop alternative management solutions.

B) Increasing the C stocks (C sequestration)
Some solutions will not be discussed in details here even if they have an high potential of sequestration: it is the case of agroforestry which offers a sustainable alternative to deforestation (Schroeder 1994) with a potential of several t/ha/yr considering both soils and trees; a better management of pastures (more than 3 billions ha for FAO) represent also an important potential for C sink C (more than O.5 t/ha/yr ?).
For cultivated lands which have the lowest and often critical organic matter content two solutions are available.
The first is to change the land occupation and to establish forest or grassland: the increase could be, referring to several expertises, of more than O.5 t C /ha /yr.
The second one is to change the agronomic practices (figure 7 from Robert 2001)
And different solutions are available(increase the inputs and decrease the losses) which are more often combined.
In order to increase the inputs, it is necessary to increase the biomass (vegetation and or organic residues).
To decrease the loss, it is necessary to decrease or suppress the tillage practices and at the same time, to cover the soil. By the way both mineralization and erosion are decreased.
Different historical agronomic systems are available: US since the years 1930 have developed the conservation tillage where the soil has to be covered for a minimum of 30 % with organic residues.
Conservation agriculture (first world meeting in 2001 in Madrid) has more strict principles: no soil tillage and a permanent soil cover either by mulch or by cover crops which implies direct drilling. The French CIRAD has developed very diverse agronomic systems adapted at the different cultures or regions (Capillon and Seguy 2002).
In figure 7, the use of anaerobiosis to protect and accumulate organic matter is available for wet lands or peat management.

III Main stakes with C sequestration

Carbon sequestration in soil is important considering the climatic change and the Kyoto protocol, but links exist with the others international conventions (on biodiversity or

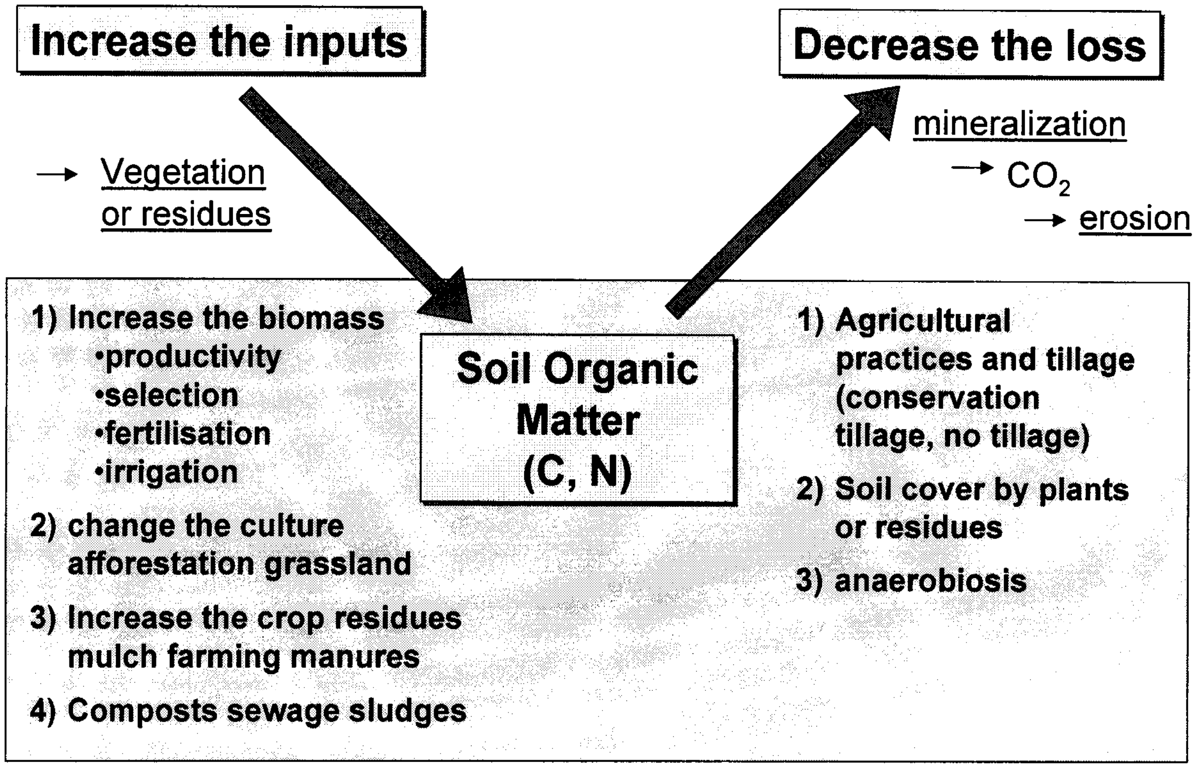
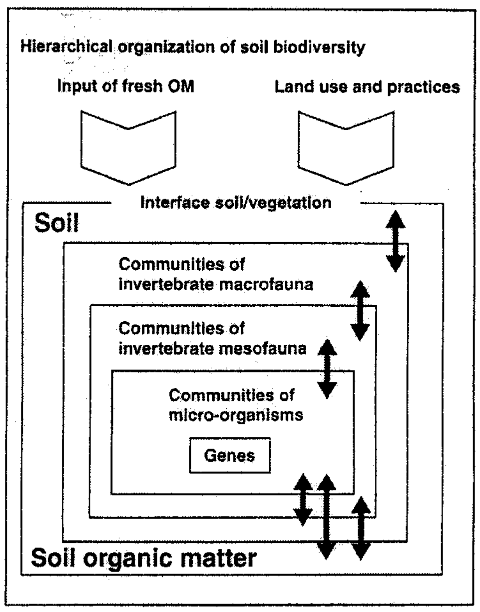


Figure 7 Management of soil organic matter in agriculture (Robert, 2001)

Figure 8 Role of soil organic matter in biodiversity (Robert,2001)



desertification). Organic matter is also a key component in soil and a key factor for soil quality and soil protection (Rees et al 2001, Doran et al 199, Chenu and Robert 2003). So a main stake concerns the sustainability of agriculture.

A Carbon sequestration and the International Conventions

Climatic change (UNFCC convention)

A lot of polemics still exist on the possibility to sequester carbon in soil. Now several expertises exist on the subject made at the world scale (IPCC 2000; Lal et al 1997, 1998, 2000; Batjes 1999; Robert 2001). More recent expertises have involved several researchers at the European scale or for a country (EECP 2003, INRA 2001). Two factors explain the differences and polemics. First an evaluation of the annual change in C stock is needed for each land use change or each practice. Differences of sequestration potential exist in relation with climate, soil type ... and there are not enough long term experimental data in the fields. So only a range of values for C sequestration is available (for example from 0.1 to 1 t C/ha/yr for no tillage). The second factor concerns the surface area which will be concerned by the changes (millions or billions of ha?).

The different scenarios for Europe or France give interesting references which are close of 1/1000 related to the global C stock of the reference area. It would correspond with a few % (3 to 5 %) if the reference is the CO_2 emission. At the world scale the potential would be close to 2 Gt C per year (for a period of time between 20 to 50 years). So the soil contribution to prevent the green house effect and the climatic change is not the solution for the long term but an immediate solution which would permit to wait to more important remediation concerning the reduction of C emission coming from energy and transport.

It would be also important that article 3.4 be included in the clean development mechanism in order to encourage, with financial support, the southern countries to choice better land managements.

It has to be noticed that in this communication only C is considered and balance including all the greenhouse gas (N_2O and CH_4 emissions) is needed.

Another important point is that a similar priority has to concern the protection of the great stocks existing in the northern part of the world which can be concerned by an increase of temperature. The question of deforestation is highly sensitive for the southern countries, but when the size of the flux (1.7 Gt) is considered, it would be important to have economic means to encourage alternative solution (ex agroforestry).

Convention on biodiversity (UNCBD)

Soil biodiversity is insufficiently known and taken into account in the convention. Soil organic matter is both a source of energy and nutrients for living organisms. Independently from climate, it represents one of the main factors which determine biological functioning and biodiversity (Soberon et al 2000). In agriculture, the others important factors are tillage and pesticides (figure 8).

Convention on desertification (UNFCCD)

Here also soil organic matter is a key factor which plays a role both in the desertification development (decrease in SOM) or in the prevention or remediation process (figure 9 Hillel and Rosenzweig 2002). This action of organic matter is linked with the development of the vegetation and the soil cover and soil protection (see conservation agriculture)

B Development of a sustainable agriculture

At the world scale erosion (by wind or water) is the main process of soil degradation.

Figure 9 Role of soil and Soil organic matter in the desertification process (Hillel and Rosenzweig, 2002)

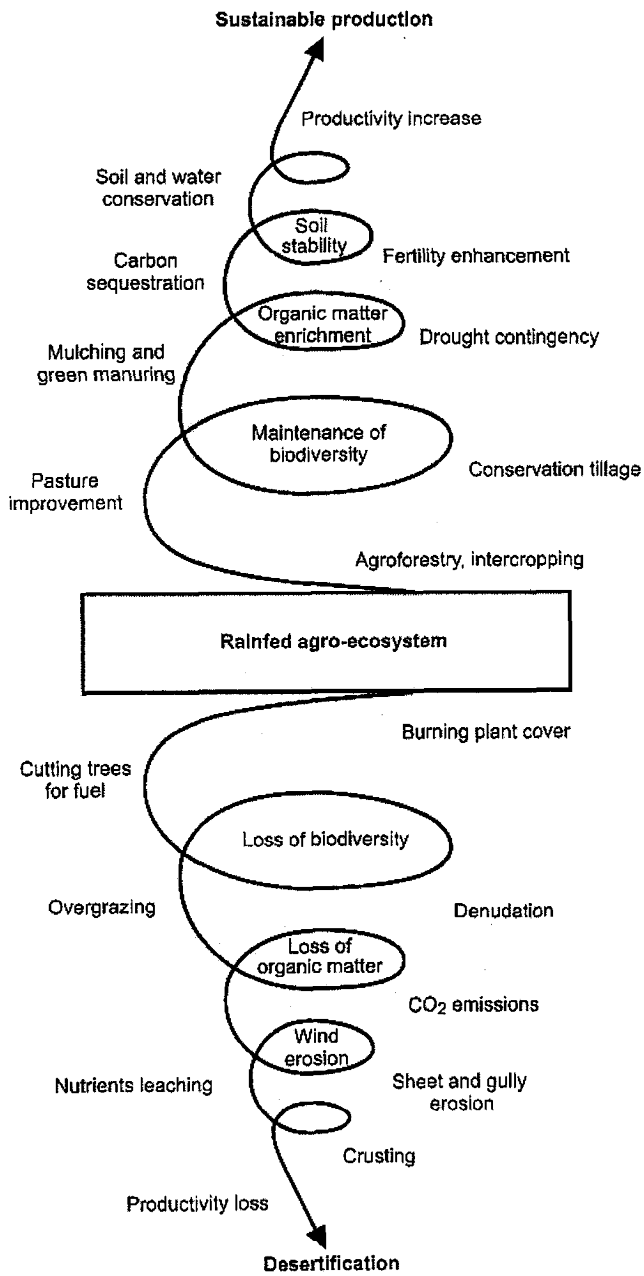


Figure 16 The upward and downward spirals of sustainable versus unsustainable rainfed agro-ecosystems.

For the Global Assesment of Soil Degradation (GLASSOD, Oldeman 1994) erosion sensitivity represents more than 1 billion ha. The main causative factors of similar importance are deforestation, overgrazing, and agricultural management.
Different methods have been developed in the past with terraces...
In US, the development since 1940 of the conservation tillage (which covers a part of the soil) seems quite effective to remediate wind erosion (dust bowl). With a complete soil coverage in South America and particularly in Brazil, the conservation agriculture succeeds to suppress the erosion by water even when the slopes are important.
Two factors are important for these agriculture systems: soil coverage by mulch or vegetation, and an increase of soil organic matter localized in different compartments. The soil quality and biological functioning are increased with positive effects on structure stability (Tisdall et Oades 1982). Soils have also a better chemical fertility with a greater recycling of the nutrients by the plants.
Conservation agriculture is developed on around 70 millions ha mainly in US, South America , Australia, Canada but the number of ha increase of 1 million ha each year.
It has other kind of benefits for the farmers: increase of yields, economy of energy and working time (Madrid 2001 conservation agriculture). It has to be noticed that some problems could occur with the use of herbicides
Europe is developing a soil strategy on soil protection with a priority for erosion (+ desertification), organic matter (+ biodiversity) and contamination. The soil protection is yet ecoconditionnal to receive the subventions of the Common Agriculture Policy (within the last reform) similarly to what is yet occurring in US. In 2004 the working groups on soil organic matter and erosion will propose common Win Win recommendations for action which will imply new forms of agriculture in Europe, may be with reduced tillage which permits the increase of both soil coverage and SOM.

Conclusion

The climatic change is the most serious problem for the 21th century. Even if there are a lot of scenarios and uncertainties, prevention and actions are necessary and all the sectors of activities have to contribute.
As it was said C sequestration in soils could have a significant contribution which is more and more precise but which involves changes in forestry and agriculture and some encouragement by politics. The important thing is that these changes seem to be beneficial for soil protection (especially against erosion) and environmental quality, which are required conditions for a sustainable agriculture; they can also contribute to the success of the three great conventions of the United Nations.

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Table 1: Total stocks of soil organic carbon (SOC) (Pg C) and mean C contents (kg C/m^2) by major Agro-Ecological Zone (for upper 0.3 m and 1m) (from Batjes, 1996)

Agro-ecological zone	Spatially weighted SOC pools (Pg C)		Mean SOC density (kg/m^2)	
	to 0.3 m depth	to 1 m depth	to 0.3 m depth	to 1 m. depth
Tropics, warm humid	92 – 95	176 – 182	5.2 - 5.4	10.0 - 10.4
Tropics, warm seasonally dry	63 – 67	122 – 128	3.6 - 3.8	7.0 - 7.3
Tropics, cool	29 – 31	56 – 59	4.4 - 4.7	8.4 - 8.9
Arid	49 – 55	91 – 100	2.0 - 2.2	3.7 - 4.1
Subtropics with summer rains	33 – 36	64 – 68	4.5 - 4.7	8.6 - 9.1
Subtropics with winter rains	18 – 20	37 – 41	3.6 - 3.9	7.2 - 8.0
Temperate oceanic	20 – 22	40 – 44	5.8 - 6.4	11.7 - 12.9
Temperate continental	121 – 126	233 – 243	5.6 - 5.9	10.8 - 11.3
Boreal	203 – 210	478 – 435	9.8 - 10.2	23.1 - 24
Polar and Alpine (excl. land ice)	57 – 63	167 – 188	7.0 - 7.8	20.6 - 23.8

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